2006 NASA SOFTWARE OF THE YEAR SUMMARY EVALUATION DOCUMENT

Identification Information	
Software Title:	**FACET: Future ATM* Concepts Evaluation Tool**
NASA Case No.	ARC–14653-1 | **(*ATM = Air Traffic Management)**
Responsible Center(s):	Ames Research Center

Software's Developmental Status	
Current Technology Readiness Level (1-9): **9**	Classification (A-H): **C**

Significance to NASA Mission Part A – Impact on NASA's Mission

FACET is a flexible software-based analysis environment for exploration, development, and evaluation of advanced Air Traffic Management (ATM) concepts. FACET has been funded by, and directly supports, the Airspace Systems Program under NASA's Aeronautics Research Mission Directorate. NASA has recognized FACET for its many contributions towards enabling a more efficient air transportation system; the FACET team received the prestigious Turning Goals into Reality (TGIR) Award in 2001 for exceptional progress towards this goal.

FACET has been utilized to guide decisions regarding the allocation of NASA resources for new Airspace Systems Program initiatives. For example, FACET-based studies have estimated benefits of $200M/year for implementation of advanced traffic flow management techniques being developed by NASA. FACET's unique capabilities as a research and development tool continue to support NASA's mission by guiding the development of the Next Generation Air Transportation System, specifically by facilitating the design of higher capacity airspace systems.

Significance to Science, Technology, & Industry in General Part B – Impact on Science & Technology

FACET has significantly impacted science and technology beyond direct support of NASA's mission. It has been utilized for successful transfer of NASA-developed technology to industry for operational use in the nation's air transportation system. Users of FACET and its derivative technologies include the Federal Aviation Administration (FAA), commercial and general aviation, large companies, small businesses, and universities.

In June 2005, a FACET-derived technology, called Reroute Monitor, was implemented in version 8.0 of the FAA's Enhanced Traffic Management System for operational use at over 100 FAA field sites. In summer 2006, the FAA will implement the Airspace Flow Program, a new technology developed by Metron Aviation, Inc. using FACET for concept development and prototyping. This tool will help reduce travel delays during the thunderstorm season.

In February 2006, FACET was integrated with a commercial product, Flight Explorer Professional FE6.0, under license from NASA. Approximately 4,700 users (in airlines and general aviation) can utilize FACET's traffic forecasting abilities to build demand/delay estimates, enabling efficient fleet operations. Initial customer reaction has been very positive.

FACET's powerful data visualization capabilities have had great success in educating university students and the general public about air traffic congestion. A movie created using FACET, depicting 24 hours of air traffic operations over the contiguous U.S., has been used by a MIT professor giving expert testimony to the U.S. Congress. The Smithsonian Institution's National Air and Space Museum is incorporating key features of FACET into a large exhibit, called America by Air, scheduled to open in 2007.

Techniques for modeling complex large-scale systems, developed with FACET, can also be applied horizontally to planning/scheduling of other large complex networks such as the internet (data communications), ground transportation systems, and power distribution grids.

Significance in Impact on the Quality of Human Life Part C

Implementation of FACET-developed advanced techniques for traffic flow management and dynamic airspace configuration will reduce delay and increase overall efficiency of National Airspace System operations. This will generate many benefits to society, as outlined below.

Environmental: More efficient flight trajectories mean less fuel burnt per flight, which has a direct impact on air quality and energy conservation. Existing trajectory synthesis and prediction models in FACET can be augmented with engine noise and exhaust dispersion models to forecast noise and emissions patterns around major population centers. These technologies enable efficient design of airways and approach paths to airports, significantly reducing the environmental impact of air traffic by minimizing noise and emissions.

Economic: The reduction of delays and improvement in flight schedule integrity improves airline profitability, which in turn benefits the U.S. economy. The ability of the NAS to accommodate higher levels of air traffic helps increase the nation's mobility, which is essential for economic growth.

Educational: The ability of FACET to realistically simulate a large complex system with many decision-makers, and its availability to educational institutions, provides a mechanism to motivate, educate, and train students in solving complex science and engineering problems.

Collectively, the benefit mechanisms described above will have a substantial positive impact on the quality of human life.

Extent of Current and Potential Use

FACET has been in operation for about seven years. The number of current users is estimated at 500 government users and 4,800 industry/university users, with several thousand potential users. NASA studies have estimated benefits of well over $200M/year for implementation of advanced traffic flow management techniques being developed using FACET; some of them are already operational, as described below.

Level of Current Use: Excellent

FACET has been extensively used in support of NASA's Airspace Systems program. It is also a centerpiece of NASA's Next Generation Air Transportation System – Airspace project.

NASA has developed a real-time version of FACET that directly interfaces with the FAA's Enhanced Traffic Management System (ETMS). ETMS is the FAA's core system, providing traffic visualization and planning capabilities on Traffic Situation Displays for roughly 500 airspace users at over 100 sites across the nation. FACET's Reroute Monitor function, deployed in 2005 as part of ETMS version 8.0, provides the FAA with a unique capability to monitor user conformance with nationally implemented rerouting initiatives.

A Space Act Agreement between NASA and Flight Explorer (FE) was signed in 2005. Flight Explorer is the world's leading provider of internet-based real time flight tracking and information systems, reporting, and display products, with a customer base of approximately 4,700 licenses. NASA has granted Flight Explorer a nonexclusive worldwide license to market key FACET functionalities bundled with their new product FE6.0, released in Feb 2006.

FACET has been released (under a Federal Government Transfer Letter or a Non Disclosure Agreement) to numerous organizations in the government, industry, and universities.
Government: FAA, NASA, U.S. Air Force, NORAD, Volpe Center (Dept. of Transportation).
Non-Government (Industry and Universities): American Airlines, Boeing, Massachusetts Institute of Technology, Northwest Airlines, Southwest Airlines, and 30 other organizations.

A complete list of over 40 current users is available in NF1329A.

Level of Potential/Planned Future Use: Excellent

The FAA's Airspace Flow Program (AFP), scheduled for implementation this summer at over 100 FAA facilities, utilized FACET for concept development and prototyping. AFP will substantially reduce travel delays, potentially saving airlines millions of dollars each year.

The Smithsonian Institution's National Air and Space Museum is incorporating key features of FACET into a new exhibit, called America by Air, scheduled to open in 2007. The museum's annual attendance is estimated at 9 million visitors from all over the world.

Optimal Synthesis, Inc. is working under a NASA SBIR contract to develop a scriptable, Java-based interface that will allow MATLAB® and Jython users to modify and operate FACET either locally or remotely from either of these widely-used environments. This version of FACET has excellent commercialization potential among air traffic control enthusiasts in the 500,000+ MATLAB® and Jython user community.

Usability of the Software

Ease of Use:

In developing FACET, great care was taken to ensure ease of use by the end customer. Continued user feedback, through venues such as the FACET-Flight Explorer User Conference, and formal human factors assessments, such as a FAA-sponsored evaluation of the FACET Graphical User Interface (GUI) and airline focus group studies coordinated through The Ohio State University, have all contributed to the usability of the software. As a result of these formal and informal studies, operation and control of the FACET GUI now takes place through a series of flexible and intuitive Java-based dialog boxes with accompanying ToolTips, preference settings, and HTML-based "Help" menus. In laying out the various menus in FACET, emphasis has been placed on supporting efficient task-flow within the system and ensuring that advanced features are not too readily accessible by the novice user. Additionally, care has been taken to ensure consistency in the labeling and use of menu items, textboxes, and dialogs throughout FACET. The net result is a highly intuitive and easy-to-use system that is capable of conducting sophisticated analyses and visualizing air traffic, airspace adaptation data (e.g., sectors, fixes, airways, airports, etc.), weather data, and wind data.

To support the diverse needs of the FACET user community, the system is capable of supporting either real-time or post-operation studies in four different modes: playback, simulation, live, and hybrid. Individual aircraft or groups of aircraft can be controlled through an extensive library of control actions that include: Playbook Reroutes, Coded Departure Routes, Miles-in-Trail, Ground Delay Programs, Ground Stops, Conflict Avoidance, Direct-Routing, and Severe Weather Avoidance. Output from FACET runs can be visualized through its extensive 2D and 3D Java Swing-based interface, written to a MySQL database, or stored in a flat file for further processing. Alternatively, connectivity to FACET from Flight Explorer, MATLAB®, Jython, and the FAA's Post Operations Evaluation Tool (POET) allows end users to access FACET functionality from systems that are already familiar to them.

Technical Support Provided:

- NASA-Ames staff and on-site contractor personnel regularly provide user assistance, problem consultation, patches, and trouble-shooting via phone, e-mail and visits.
- Users on the ClearCase software configuration management tool can get bug-tracking, software and documentation updates instantaneously.
- Powerful customer support from Flight Explorer personnel is available for FACET-related queries to their entire client base.

User Documentation:

Electronic and hard copy versions of a 100+ page user manual, step-by-step storyboard scenarios for common FACET tasks, and embedded HTML help documentation form the core of the FACET user documentation. Collectively, this documentation describes all of the system's capabilities, common uses, installation instructions, and data formats.

Availability of Training:

To meet the training needs of the diverse FACET user community, an extensive two-day self-paced or on-site training curriculum has been developed. Included in this curriculum are sessions on current and future applications, data sources and formats, interactive demonstrations, and problem solving sessions. Recent trainees include representatives from the FAA, airlines, universities, and industry. Additionally, the Flight Explorer user community, which numbers in the thousands, can also access FACET training material directly from the company's website. The most recent FACET training session was conducted May 11-12, 2006 at the FAA's Air Traffic Control System Command Center.

Quality Factors Considered in Software

Reliability:

To ensure the highest level of system reliability for our academic, government, and industrial user base, numerous fail-safe, data cleansing, and self-diagnostic systems have been built into FACET. Among the most important fail-safe features employed in the system are: Java thread locking, Java exception handling, error logging, redundant trajectory prediction algorithms, and the use of data proxy servers to handle real-time data stream connectivity issues. Once data are ingested into FACET, extensive filtering, especially for aircraft radar return reports, data type checking, and data size checking is performed to verify the integrity of data entering the system. In the event that erroneous data are received by the system, the systems error logging software will record the event for further investigation. Additionally, all flights exhibiting erroneous behavior (e.g., lacking position report updates or flight plans) are identified to the user on the FACET GUI through multiple visual cues. The last and arguably one of the most important components of FACET is the self-diagnostic toolbox that is resident in the system. This suite of capabilities is used to quantifiably measure the system's predictive reliability, the number of aircraft lacking flight plans, and the number of aircraft exceeding known flight performance characteristics. Collectively, these capabilities are able to probe every critical aspect of the system. Results from these self-diagnostic tests are displayed to the user in a number of useful formats, which include on-screen visual cues, graphs, flight lists, and ASCII formatted output files.

Functionality:

At the highest level, the end user's requirements for FACET called for the development of a highly flexible and configurable system, capable of operating on inexpensive COTS hardware to support both real-time and post-operations studies in the field of air traffic management. As illustrated by the strong testimonials in the accompanying reference letters from our academic, government, and industrial users, FACET has met or exceeded every requirement set forth by our user community. From the academic and government researcher's perspective, the large numbers of publications documenting studies utilizing the system's capabilities are evidence of the system's utility. Similarly, Flight Explorer's success in licensing, integrating, and operationally deploying FACET with their commercial product confirms that the FACET team has developed a system that meets or exceeds the end user's requirements.

Performance:

In the field of air traffic management, the performance capabilities of FACET are unsurpassed by any commercial or government developed software applications. Using a commercially available 3.0 GHz laptop computer with 1 GB of RAM, FACET can: (1) simulate and display 24 hrs. of data or 60,000 flights in 15 minutes, or (2) rapidly build 4D trajectories for 10,000 flights and display sector, airport, fix, and airway usage statistics in under 10 seconds. Systems currently used by the FAA and airlines, which possess far less functionality, run on enterprise level servers that are orders of magnitude more expensive and slower than the inexpensive COTS hardware used by FACET.

Reuse:

FACET is a Java-based object oriented software system that was designed with industry standard design patterns. The result is a highly scalable, extensible, and modular system that is easy to integrate with existing or proposed systems. This point is well illustrated by the ability of our industry partners to seamlessly integrate select modules of FACET with Flight Explorer, MathWorks' MATLAB®, and the FAA's Post Operations Evaluation Tool (POET) systems. In addition, the Reroute Monitor application developed in FACET was also implemented in the FAA's operational Enhanced Traffic Management System (ETMS) version 8.0 in June of 2005.

Maintainability:

The maintainability of well-designed object-oriented software systems, such as FACET, is well documented in the literature. To ensure the continued maintainability of FACET, ClearCase is used for software configuration management, while defect and change tracking is accomplished using ClearDDTS. All FACET developers must complete a web-based ClearCase/ClearDDTS training module, which documents the software change procedures, prior to modifying the software. As a result of the object-oriented design of FACET and the rigorous software management procedures that we have instituted, software developers from our industry and academic partners are currently working harmoniously on FACET. Each of these entities routinely develops and tests FACET on such diverse operating systems as Solaris, Linux, Mac OS X, and Windows 98/2000/NT.

Efforts to Transfer/Commercialize Software	
Description of Plan/Strategy to Transfer/Commercialize Software	NASA has granted Flight Explorer a nonexclusive worldwide license to market and bundle basic FACET functionalities with its product FE6.0, released in February 2006. Planning is underway for new commercialization opportunities with other companies, such as Google and MATLAB®.
NASA Intellectual Property Status/Potential	• NF1679 and CTO-6 are on file at the NASA-Ames Commercial Technology Office. • Patent rights have been assigned to NASA on NF434. • Patent was filed in 2004, and is currently being processed.
Commercialization Potential for the software.	FACET has already been commercialized under NASA's licensing agreement with Flight Explorer, with 4,700+ users.
Dates Software released for commercial or program use	Released to over 40 organizations (govt., industry, universities) Over 5,000 current users.

List all existing licenses and/or partnership agreements for the software	• Non Disclosure Agreements (Project Release or Beta Testing) with 35 non-government organizations. • Federal Government Transfer Letters for 7 organizations. • Licensing Agreement with Flight Explorer.

Innovation (Creative New Features, Solutions, and Achievements)

Currently, no other software combines the flexibility of FACET together with its wide array of applications useful to Air Traffic Management and other large complex engineering systems. There are four modes of operation in FACET: (a) Playback mode to depict and analyze historical data, (b) Simulation mode for predicting the evolution of traffic data, (c) Hybrid mode utilizing historical data for "what-if" type analyses, and (d) Live mode for real-time display/analysis of actual traffic data. These modes enable FACET to integrate the roles of an analysis tool and a real-time planning tool for researchers, airline dispatchers, and air traffic managers. The advances in FACET are achieved by combining novel ideas from computer science, aircraft guidance and control, computational algorithms, visualization techniques, and human factors. FACET's ability to simulate a large complex engineering problem with multiple decision-makers represents a major breakthrough in the level of decision support software available for systems with distributed decision-making.

FACET is the first software system available to the air traffic community that provides both a flexible and highly adaptable simulation and modeling environment, while also providing the performance and reliability required for development and evaluation of ATM tools for real-time operational use. These capabilities are largely due to the innovative software architecture employed in FACET, which seamlessly merges the Java and C programming languages. The resulting system is highly efficient, portable, modular, and extensible.

To achieve the performance capabilities required for FACET, several innovative techniques were developed. Some notable examples are: (1) Achieving an order of magnitude reduction in computation time by recognizing that rerouted air traffic count is a linear function even though the corresponding aircraft trajectories are nonlinear; (2) Utilizing a grid-based search method for rapidly identifying the location of an aircraft in the NAS – this capability is invaluable when monitoring the capacity of the NAS and identifying areas of potential congestion; and, (3) Utilizing pre-calculated climb, descent and cruise profiles – this enables rapid calculation of aircraft trajectories. These techniques are largely responsible for FACET's ability to perform real-time modeling and traffic analysis of more than 10,000 aircraft over the Continental U.S. on an inexpensive COTS laptop computer, and makes FACET an extremely attractive modeling and simulation tool for engineers, FAA, airlines, industry, and universities.

While supporting NASA's mission, new software technologies have been developed in FACET, which allow the user community to study air traffic controller workload, flight deck based conflict detection and resolution, direct-to routing, air and space traffic integration, traffic management initiative evaluation, and system-wide optimization. Each of these applications employs original methods and processes to perform its respective tasks within FACET. The integration of these innovative methods and new software technologies in one system represents original contributions to the state-of-the-art of ATM software, and in the simulation of large complex engineering systems. FACET plays an increasingly significant role in the exploration of new ATM concepts to realize the goal of safely increasing the capacity and efficiency of our aviation system.